AUTHOR:
Rina Durandt
Mathematics Education, University of the Witwatersrand
Johannesburg, South Africa
Wilmari Morton
Mathematics and Applied Mathematics, University of Johannesburg
Johannesburg, South Africa
Vaughan van Appel
Statistics, University of Johannesburg
Johannesburg, South Africa

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Exploring effect variables on learning first-year mathematics in a context-specific blended learning environment: Lessons following the COVID-19 pandemic

Abstract

This paper reports lessons learnt following the pandemic, particularly the effect of key variables on learning mathematics in a context-specific blended learning environment, such as the availability and accessibility of technological resources and students' self-directed learning. The pandemic (COVID-19) caused unprecedented disruptions in education in 2020 and 2021, with a ripple effect in the years following the pandemic. Lockdowns forced students and university teachers (lecturers) worldwide into an online learning environment, influencing performance. By 2022, with partial restrictions still in place, students and teachers could adjust and advance. To optimise the learning experience, we developed and implemented a blended learning environment suitable for the context: a first-year mathematics class at a large public university in South Africa. Ninety-nine student experiences were explored using a self-designed questionnaire. Additionally, the relationship between variables and performance was examined using the Chi-square test of independence. We identified several variables that influenced student performance relating to their background and self-directed learning habits. There was no statistical evidence that the type of technological access affected student success in this study. Ways to navigate around these variables should be considered when teaching in disruptive situations.

Keywords: *Blended learning environment, Context, Disruptive times, First-year mathematics, Mathematics performance, Pandemic, Reflective practice, Self-directed learning, Technological resources*

1. Introduction

The question "When all this is over, how do you want the world to be different?" appeared on a board sign in a public park in London during the pandemic (Shafak, 2020). The question refers to a former disruptive time and, from a philosophical perspective, lessons learnt from

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that time that can contribute to a current or future better world. The COVID-19 pandemic caused unprecedented disruptions in education globally, at all levels, and in all subject fields. For example, the pandemic pushed forward the agenda of the digital technology trend in mathematics education (Borba, 2021). On the one hand, disruptions in education can cause a crisis in knowing and confidence, but on the other hand, it can also create fast opportunities for creativity (Dison, Prozesky, Ferreira, Essien & Giorza, 2024). The crisis in knowing and confidence is usually centred around questions related to mental health, the pedagogical preparedness of teachers and students, and questions related to the quality of education. One example of a creative approach to deal with the challenges caused by the pandemic is from an engineering mathematics class (Durandt, Herbst & Seloane, 2022). The approach included key elements such as an evaluation of prior knowledge by a diagnostic test, an investigation of students' attitudes towards mathematics, weekly virtual lecture and tutorial sessions, weekly homework tasks, additional online resources, discussion forums between role players, online tutor support, the use of e-textbooks and online assessments via the university learning management system (Blackboard) and an external platform (WeBWorK).

Four years later, the pandemic has passed, and other disruptive situations around the globe persist or have developed. Several countries are experiencing disruptions in education related to civil unrest, war, and displacement, such as Ukraine (see Kenworthy & Opatska, 2023), Palestine[1] and Sudan[2]. Other countries are experiencing educational disruptions related to cultural and language difficulties, which arise through the hosting of refugees (e.g., Germany, see Schipolowski, Edele, Mahler & Stanat, 2021). Another global example is related to COVID-19 learning losses and historical factors (e.g., South Africa, see Di Pietro, 2022). More recently, natural disasters like the wildfires in Los Angeles have also caused significant disruptions to education[3]. It is unknown how the current disruptions, independent of the cause, will change the education agenda and how students and teachers will manage the changes.

The design of new teaching settings, in a very short time frame, was essential during the pandemic and 'business as usual' could not continue. National lockdowns prohibited face-to-face teaching, and the new teaching settings necessitated the use of technology. Using the example of tertiary mathematics education, we know that plenty of research exists on offering online course components (e.g., Engelbrecht & Harding, 2005; Quinn & Aaräo, 2020), but the sudden and forced change to online learning at the time of the pandemic was unfamiliar to students and lecturers (e.g., Durandt et al., 2022; Chirinda, Ndlovu & Spangenberg, 2021). Some students, particularly in developing or low-income countries or countries with pre-existing inequalities in education, had unequal scenarios related to the availability and accessibility of technological resources and less flexibility to self-regulate their learning (see Morton & Durandt, 2023). Consequently, educators should learn how to implement curricula that address social inequalities that come to the forefront, especially during disruptive times (see the example from Brazil in Borba, 2021) in our current volatile world. More research that provides deeper understanding is needed in this area, drawing from both current disruptive classrooms as well as through reflections on former practices. The question arises: What can we learn from the past to navigate through unexpected changes in our teaching settings while fostering students' self-directed learning?

1 https://www.un.org/unispal/document/palestinian-education-under-attack-unrwa-25sep24/
2 https://www.cfr.org/global-conflict-tracker/conflict/power-struggle-sudan
3 https://www.npr.org/2025/01/10/nx-s1-5254509/fires-la-school-students

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Towards the end of the pandemic, in February/March 2022 in South Africa, when students returned to the university campus, regulations followed from the government and university management to further adapt to the 'still disruptive' situation in education. One example was the restriction on fifty percent venue capacity (e.g., a venue with a capacity of 100 students could not allow more than 50 students). Again, lecturers faced a sudden change in the learning environment and several practical challenges. Previous models, 'business as usual' from the pre-COVID era that primarily involved face-to-face classrooms and 'forced online learning' from the COVID era that only involved learning at a distance, were unsuitable for practical reasons. Examples, from the authors' own experiences, of practical challenges/questions were: (i) how to organise multiple class groups in one course while taking into account the restrictions on venue capacity, (ii) how to blend and synchronise the face-to-face and online components, (iii) how to plan for the unequal scenarios between students and contextual aspects, and (iv) how to monitor students' learning? Pedagogic innovation and the exploration of innovative learning possibilities seemed necessary during this disruptive time (compare Dison et al., 2024). Against this background, we conducted a study at the start of 2022, reflecting on what we learnt during the pandemic (2020 & 2021, also see Morton & Durandt, 2023) as an attempt to learn from former practice, where we developed a context-specific blended learning environment for first-year mathematics students as a step in the direction of innovation.

2. Conceptual framework

The theoretical concepts that informed this study were selected to construct a context-specific blended learning environment for tertiary mathematics that supports students' self-directed learning. We followed mainly ideas from Borba, Askar, Engelbrecht, Gadanidis, Llinares and Sánchez-Aguilar (2016) that provided guidelines for the design of the blended environment and work from Pintrich (2000) to inform our understanding of self-directed learning.

2.1 Learning in a blended learning environment

Three main factors should be addressed when educators design online or blended learning environments. These are *principles of design*, *social interaction and construction of knowledge,* and *tools and resources* (see Borba et al., 2016; Engelbrecht, Llinares & Borba, 2020b).

The *Principles of design* guide mathematics educators to construct a mathematics teaching context. This study focused on a blended approach for practicality and efficiency. Integrating face-to-face and online components can be done synchronised or asynchronised. The general understanding is that synchronous engagement occurs when lecturers and students are together in the same environment at the same time when learning occurs (this can be in a face-to-face or online classroom). However, with asynchronous engagement, lecturers and students interact at different times (for example, lecturers post notes on the online learning environment, and students access the notes over a period). The idea is to be thoughtful about the blend, and no 'one-size-fits-all' approach can be applied (see, for example, work from Alammary, Sheard & Carbone, 2014). The blend depends on the course, the instructors, and the situational context and should allow educators to care for a diverse student community. This study considered synchronised and asynchronised ways to accommodate contextual factors (see section 4).

The *Social interaction and construction of knowledge* strand is situated in the work of Vygotsky, particularly social constructivist learning theory, and is used to improve student engagement and learning in courses. Several examples applying different perspectives about learning and knowledge can be found in the literature (e.g., Cendros-Araujo & Gadanidis, 2020; Fernández, Llinares & Rojas, 2020). This study focused on constructing knowledge online to provide a scaffold for learning mathematical topics and a logical flow from one topic to another.

The third strand, *Tools and resources*, focuses on new digital technologies that provide new opportunities for mathematics educators. In the literature, different approaches to digital tools can be found, and these contribute to changing the relationship between mathematical knowledge, learners and teachers (e.g., Oechsler & Borba, 2020). This study used tools (e.g., WeBWorK) to design assessment tasks and access students' mathematical work (see section 4).

2.2 Self-directed learning

The idea of self-directed learning (SDL) includes an investigation of the characteristics of the student, his/her perceptions of the learning context, and approaches to learning. Self-directed learning can be defined as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453). We argue that the learning environment and learning pathways constructed by the lecturer can foster SDL on the students' side. Mentz and de Beer (2021) reason SDL is a 'sine quo non' for our complex world and should be the gold standard in all educational sectors. In tertiary mathematics, first-year students often lack self-directed study habits (see reports from Quinn & Aarão, 2020). However, in this study, we expected students to demonstrate SDL.

3. Research questions and hypotheses

This paper aims to explore the effect of key variables on learning first-year mathematics in a context-specific blended learning environment specifically designed to accommodate the regulations near the end of the pandemic. Key variables are the availability and accessibility of technological resources and students' self-directed learning. Ultimately, the aim is to reflect on practice and lessons learnt from the past and to use the wisdom to steer current and future disruptive times in tertiary education settings.

The research questions informing this study were:

i. *What effect does access to technology and the Internet have on first-year mathematics students' performance in a blended learning environment in the context of disruptive times?*

ii. *What measures are associated with self-directed learning of first-year mathematics students in a blended learning environment in the context described above (in question i)? Further, do these measures have a relationship with students' performance?*

Informed by the Morton and Durandt (2023) study, we expected a significant effect between students' access to technology and the Internet and their performance in mathematics. One reason reported previously is a substantial difference between the final continuous assessment mark of students with access to a smartphone compared to students with access to more than just a smartphone. Further, informed by previous results (Morton & Durandt, 2023), we expected a strong correlation between students' self-directed learning and their performance in mathematics. The context-specific blended learning environment in this study will require students to be active and constructive in their learning processes, and former results from a fully online environment showed that the time spent studying mathematics did not seem statistically significant on performance. However, students' engagement with the content proved significant.

In the next section, we describe this study's context, sample and design. We provide details about the context-specific blended learning environment, mainly the face-to-face and online components, and how they were integrated. The two research questions are answered in the paper's results section (see section 5). Finally, we discuss the results as a reflective practice to inform future practice (see section 6).

4. Design and methodology

4.1 Context and sample

At the start of 2022, both lecturers and students had to adjust again, as a return to campus became necessary, even though they were bound by restrictions on venue capacity (maximum 50%). In a typical year, with face-to-face instruction, venues are mostly occupied to full capacity. Thus, in 2022, the need arose for a blended approach, including both synchronised and asynchronised elements. Quantitative data were collected from the first-year mathematics students at a large public university in Johannesburg during the first semester of 2022 (see more details about the sample in section 5). Most students in the sample experienced disruptions in their secondary education (grade 11 in 2020 and grade 12 in 2021).

The sample was self-selecting as the questionnaire was made available to all 370 students in the course, and participation was voluntary. Sample selection through probability methods is preferable (Tanur, 1983) but not possible in this study, which has the potential shortcoming of selection bias (e.g., Lohr, 2021, Chapter 1) because participants and non-participants differ in their behaviour and attitudes (Watkins & Hattie, 1985). In total, 106 participants completed the questionnaire, with 99 valid responses with no missing data (valid response rate of 26.8%). Another potential limitation is that the second author of this paper had a dual role as researcher and lecturer. To control this limitation, we collected data online to avoid interference from course lecturers.

4.2 Elements of the context-specific blended learning environment

The first-year mathematics course was structured so that each student was assigned to a lecture group (one of three groups), and each lecture group was assigned 50% of the usual contact time where students attended class in person (face-to-face). Class attendance was compulsory and monitored by the group lecturer, and teaching and learning took place in a synchronised way. Total in-person contact time per group per week was 135 minutes (3 periods on the university timetable). The different group lecturers followed the same approach. In this teacher-directed approach, the lecturer revised the content and completed more examples in class, and students were asked to take part in problem-solving tasks related to the content. They had an opportunity to interact with the lecturer in class (e.g., by asking questions).

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The remaining 50% of contact time was online, and teaching and learning took place in an asynchronous manner. The online platform's learning material (including pre-recorded videos, lecture slides, tutorial exercises and access to an e-book) was released to students at the start of each week. Students were expected to engage with the content online for at least 135 minutes per week (equivalent to 3 periods on the university timetable) before they attended the in-person class. Students' interactions were sometimes more passive (like watching the pre-recorded videos) and sometimes more active (like working on tutorial exercises).

The course content includes topics on logic, precalculus, and calculus and was presented over 14 weeks. Each class had a course tutor who could assist students in class (in groups or individually) and online. A blended approach was followed for assessment tasks. Formative assessments consisted of weekly online quizzes through the WeBWorK platform or the university's learning management system. The summative assessments, consisting of two major tests and the formal examination, were written on paper on campus, and standard university procedures were followed. At the end of the semester, a final semester mark was calculated – students with a mark of 40% or higher were allowed to write the final examination. An average of 50% or higher between the semester and examination marks was needed to pass the course. Table 1 shows the organisation of course content and assessments as well as the synchronised and asynchronised elements.

4.3 Data collection instruments

The questionnaire was designed in 2022 for students exposed to the specific blended learning environment in 2022. The questionnaire consists of 36 items (see Appendix section), each of which falls into one of the following four categories:

- Characteristics of the sample
- Participants' prior learning experiences (in 2020 and 2021)
- Digital and technological resources available to participants (in 2022)
- Self-regulating study habits of students (revealed in 2022)

The questionnaire was made available to students via Google Forms for two weeks, from April to May. All registered students were invited to participate via email through the university's learning management system (Blackboard). The invitation included information on the purpose of the study, the availability window, and how to submit a response. Thus, after informed consent, students could participate in the study. Efforts were made to reduce the threats to validity during the developmental phase of the questionnaire; a mathematical subject specialist and a statistical expert were consulted.

Table 1: Organisation of the blended learning environment

Week	Online component (asynchronised teaching & learning)	Face-to-face component (synchronised teaching and learning)	Assessment
1	Numbers, inequalities and absolute values Trigonometry	Revision of prior knowledge, additional tutorial problems	
2	Sigma notation Complex numbers		Quiz 1 (online)
3	Propositional logic		Quiz 2 (online)
4	First-order logic Methods of proof		Quiz 3 (online)
5	Mathematical induction Functions and mathematical models A catalogue of essential functions		Semester test 1 (in-person and pen-on-paper)
6	New functions from old functions Exponential functions Inverse functions and logarithms		Quiz 4 (online)
7	The tangent and velocity problems The limit of a function Calculating limits using the limit laws		Quiz 5 (online)
8	The precise definition of a limit Continuity		Quiz 6 (online)
9	Limits at infinity and horizontal asymptotes Derivatives and rates of change The derivative as a function	Revision and additional examples of content introduced first online during the previous week	No assessment due to the numerous public holidays in this term period. Students were allowed to revise or catch up on work missed.
10	Derivatives of polynomials and exponential functions The product and quotient rules Derivatives of trigonometric functions		Quiz 7 (online)
11	The chain rule Implicit differentiation Derivatives of logarithmic functions		Quiz 8 (online)
12	Logarithmic differentiation Hyperbolic functions Indeterminate forms and L'Hospital's rule		Semester test 2 (in-person and pen-on-paper)
13	Antiderivatives Areas and distances The definite integral The fundamental theorem of Calculus		Quiz 9 (online)
14	Indefinite integrals The substitution rule		Quiz 10 (online)
			Examination (in-person and pen-on-paper)

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5. Results and methods of analysis

Although sample bias is inevitable in our study (as outlined in section 4.1), the realised course pass rate for the course population and the sample are not far apart during the 2022 academic year, as shown in Table 2. We, therefore, assume the sample represents a reasonable reflection of the actual population success, and we can make inferences from it.

Table 2: Course pass rate

	Sample	Population
Course pass rate	67%	60%

5.1 Characteristics of the sample

There is strong evidence that the characteristics of students entering a mathematics course can have a significant effect on the student's success (or failure) in the course (see, e.g., Lubishtani & Avdylaj, 2023; Schipolowski et al., 2021 & Ribeiro, Rosário, Núñez, Gaeta, and Fuentes, 2019). For example, South Africa has a diverse population with more than 35 languages spoken (of which 12 are official languages). To effectively design a blended learning environment that supports and fosters mathematics learning, we must first identify the characteristic variables. These variables could serve as early risk identifiers, where students who enter the course with characteristics associated with a higher risk of failure can be monitored more closely and supported (Van Appel, Pretorius & Durandt, 2024; Ribeiro, 2019).

To specifically test the strength of the relationship that students' background may have on their experiences of blended learning and their performance (i.e., passing the course) in our study, we considered six questions (numbers 2, 3, 8, 10, 16 and 17, see Appendix) related to student background and compared how these responses related to the student's performance in the first-year mathematics course using the Chi-square test of independence. The results are shown in Table 3. This test measures the statistical relationship between two categorical variables (non-numeric) (Lohr, 2021, Chapter 10; Dodge, 2008, p. 79).

The two questions (numbers 3 and 8, see Appendix) that provide information on students' prior knowledge and background, which has a very strong statistical relationship to their success, are their home language (p-value = 0.0039) and the symbol they obtained in grade 12 for mathematics (p-value = 0.0089). Further, gender and the students remembering their grade 12 mathematics syllabus have a statistical relationship (p-value = 0.0868 and p-value = 0.0597, respectively) with course success at a 10% significance level.

To further assess the relationship between the students who passed and failed, we show the conditional distribution of the responses (x-axis) conditioning on whether the student passed or failed (as the figure label) in Figure 1. If there were no relationship between the question and course outcome, we would have a near-identical distribution of responses for the students who failed and those who passed. In other words, a student's outcome (pass/fail) in the course does not depend on the answers given in the questionnaire.

From the sample, we can observe (see Figure 1(a)) that a higher proportion of the students who passed had English as their home language (27%) than the students who failed (3%). Similarly, students who failed the course comprised a higher proportion of non-English as their home language (97%) than students who passed (73%). Students who passed showed a

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higher proportion of marks in the 80-100% (A-symbol) interval for their grade 12 mathematics mark (64%) than students who failed (30%) (see Figure 1(b)). Therefore, the sample suggests that English home language-speaking students and a high grade 12 mathematics symbol (80-90%) are statistically more likely to pass the course. Although we are not comparing a blended learning environment to a face-to-face environment here, it is possible that a blended environment with content, such as videos and additional learning material that can be accessed multiple times, and online quizzes can assist students who are not English first language speaking over regular face-to-face learning. However, this will be left for a future study.

Table 3: Results for the Chi-squared independent tests for questions related to students' characteristics and whether they passed the course

Question ID		*p*-value
2	Gender: (male/female)	0.0868
3	Home language: (English/other)	0.0039
8	Symbol (percentage) for mathematics in grade 12: (A, B, C, or D)	0.0089
10	Grade 12 schooling board: (A-levels, IEB, NSC)	0.4703
16	My matric symbol is a fair reflection of my understanding of the grade 12 mathematics curriculum: (Agree or Disagree)	0.7089
17	I remembered the school mathematics curriculum well, and I have been able to use the content in first-year mathematics at the university without any revision: (Agree or Disagree)	0.0597

Note: The variables with a significant relationship (p-value < 0.05) with course success are highlighted.

The results show that characteristics such as home language and prior knowledge play an important role in student success and should be considered in designing teaching and learning experiences for students.

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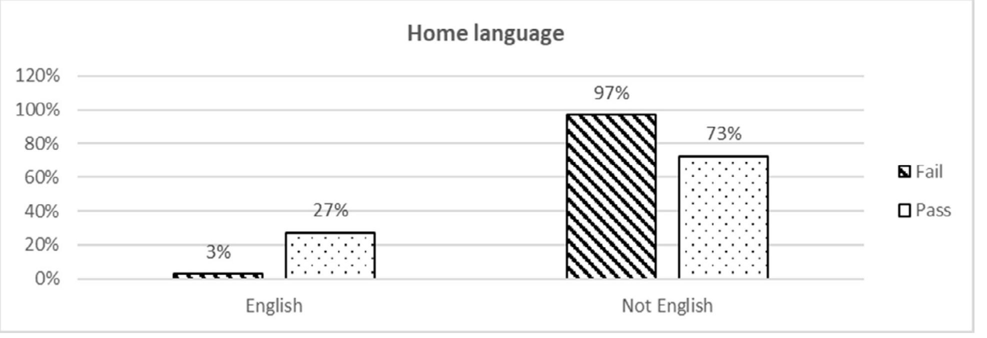
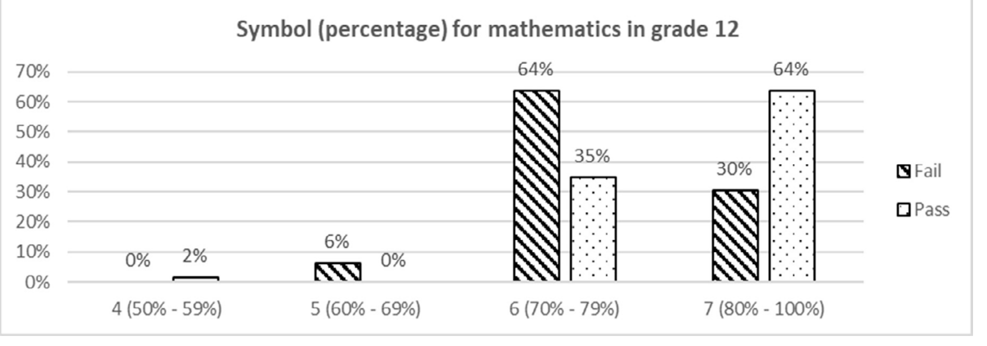


(a) Conditional distribution of home language given course outcome



(b) Conditional distribution of grade 12 mathematics symbol given course outcome

Figure 1: The relationship between student background and course success

5.2 First-year students' accessibility to technological resources

Access to technology and electricity (power) are both essential components for a blended learning environment during disruptive times, especially in the South African context where students often had to navigate access to power[4], devices and network availability. Student access to reliable technological resources was found to be important for both self-directed learning and online learning (Morton & Durandt, 2023; Engelbrecht et al., 2020b; Borba et al., 2016). Our focus in this section is on the impact of access to technological resources on the student's performance in the South African context. From our sample, we observed a significant relationship, at a 10% level of significance, between students' success in the course and whether the area they lived in had regular power outages (p-value = 0.0889), with no significant relationship between students' success in the course with access to technological devices and the Internet (question numbers 19, 20 and 22, see Appendix) at a 10% level of significance (see Table 4).

4 When the electricity demand exceeds the available supply in South Africa, *load shedding* is implemented by Eskom, which is a controlled process of reducing the power supplied to a grid to protect the electricity power system from a total blackout. At the time of this study, interruptions in the power supply (caused by load shedding) often occurred.

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Table 4: Results for the Chi-squared independent tests for questions related to students' access to technology

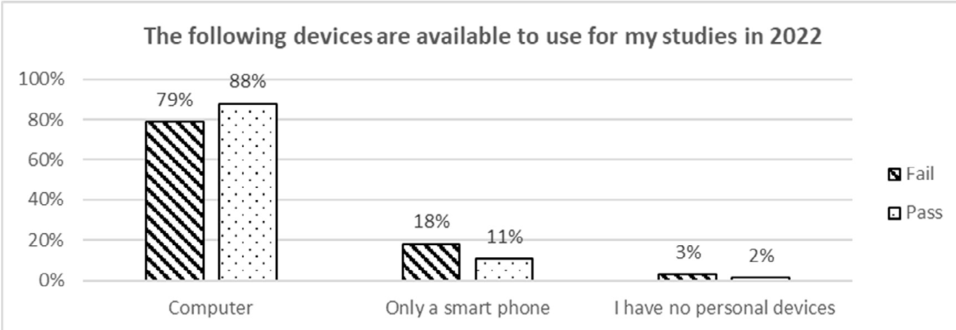
Question ID		*p*-value
18	The area where I live now (while studying at the university) has power outages (no electricity): (*almost every day, only during official load shedding, etc.)*	0.0889
19	In 2022, I can access the Internet (24 hours or only night owl hours): *(Any time of the 24-hour day, only during night-owl hours)*	0.8211
20	I have the following devices available to use for my studies in 2022: *(computer, smartphone, no device)*	0.4171
22	I have to share the device(s) available to me for online learning in 2022: *(yes, no)*	0.5163

Although access to devices and the Internet might be a struggle for many students in South Africa, this was not evident in our sample, with 89% of the sample indicating they have 24-hour Internet access and 11% having only access to night-owl Internet. Further, we found no statistical relationship between internet access times and student success in the course (p-value = 0.8211). This result is contradictory to Morton and Durandt (2023). However, it must be noted that their study was conducted during a period of abrupt and 'forced' online learning, where many students needed to return home during the lockdown, primarily to rural areas far away from the university campus, where access to the Internet and a stable power supply was more challenging. The environment in the Morton and Durandt study was significantly different to this study, where students and lecturers have since adapted to online learning practices and are more prepared for sudden changes (see, e.g., Durandt et al., 2022; Engelbrecht, Borba, Llinares & Kaiser, 2020a).

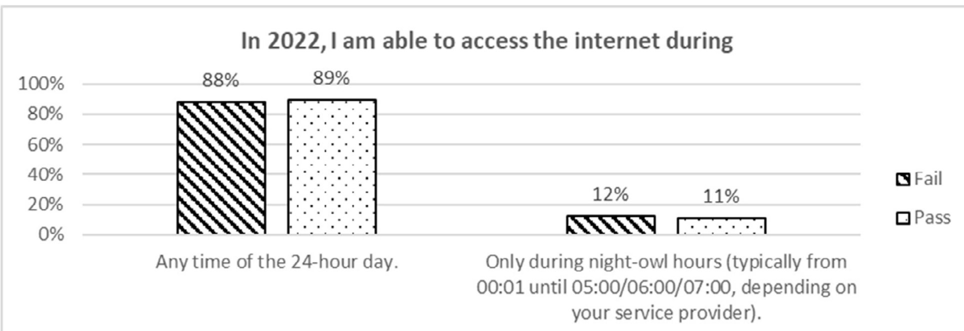
Only two students in the sample indicated: "I have no personal device" (see Figure 2(a)). However, in a follow-up question, both students indicated they used the university's *24-hour open* computer laboratories to access online material. Access to only university resources may not be ideal for a fully online learning approach, but certainly acceptable in a blended learning environment with on-campus contact sessions.

The results also showed that most students had 24-hour access to the Internet through their own devices (95% of the sample). We found no relationship (p-values > 0.05) between these two variables and passing the course (see Figure 2(b), Figure 2(c), and Table 4).

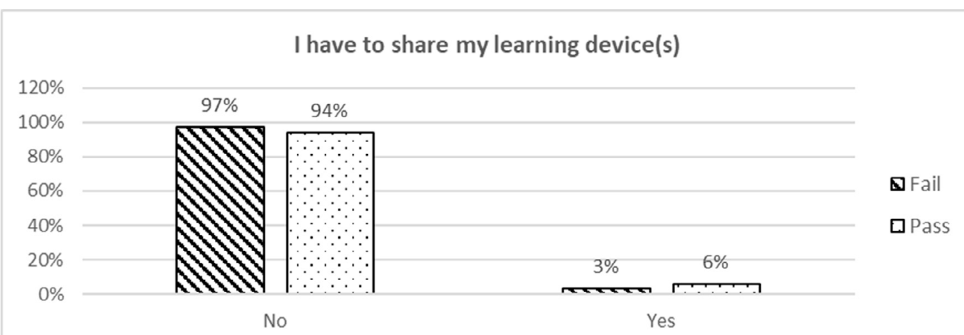
Another concern for a blended learning approach is consistent access to a stable electricity supply. The lack thereof can drastically affect students' use of technology. There is some indication in this study that power outages affected the students' success in the course, which is a concern for lecturers (p-value = 0.0889, see Table 4). Many students indicated that they seldom had power outages outside their area's allocated load-shedding schedule, and many had access to backup power supplies (72% of the sample). We note that while technology played a significant role in learning during COVID-19, the negative effect that the reduced access to technological resources at home had on individual students was mitigated by the fact that students had access to the campus and could rely on the university's resources.



(a) The conditional distribution of available devices given the course outcome



(b) Conditional distribution of times of internet access given the course outcome



(c) Conditional distribution of sharing devices given the course outcome

Figure 2: The relationship between students' accessibility to technological resources and course success

In summary, we found that most students had sufficient access to technology during our study, with no statistical evidence that the type of device, hours of internet availability and electricity supply influenced student results in the course.

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5.3 First-year students' self-directed learning

Students' self-directed learning habits are another important component of an effective blended learning environment. Pintrich (2000) mentioned several variables associated with SDL (see section 2.2). This section of the paper explores some SDL-related variables and how they relate to student success in the course. From two multiple-response questions (numbers 29 and 33, see Appendix), we summarise the sample proportions of students' SDL in Tables 5 and 6.

Table 5: Students' self-directed learning habits showing how they allocate their time while learning mathematics

Time allocation	Proportion of the sample
Attend in-person contact sessions.	86%
Read through the lecture slides and notes.	84%
Watch videos (posted by the lecturers or on YouTube).	76%
Complete assessments.	73%
Practice tutorial problems.	60%
Read the relevant section in the textbook.	38%
Communicate with my friends about the content and tasks.	35%
Communicate with the lecturers or tutors about the content and tasks.	18%

Table 6: Students' self-directed learning habits showing how they learn for a mathematics assessment

Aspects of students' preparation	Proportion of the sample
I read the class notes and slides.	66%
I watch video examples.	60%
I attempt the problems from past papers before looking at the solutions.	52%
I write down the theory (rules and theorems) to remember them.	49%
I read the relevant sections in the textbook.	43%
I practice problems from revision exercises that include multiple topics.	41%
I practice several problems on each topic.	39%
I practice only a few problems on each topic.	29%
I read through the memorandums of past papers without attempting the problems myself.	13%

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Most students' weekly mathematical activities (on how they allocated their time while learning mathematics) consisted of attending in-person contact sessions (86%), reading through the online lecture material (84%), watching YouTube videos (posted online by the course lecturers) (76%), completing assessments (either online or in-person) (73%), and practising tutorial problems that were posted online (60%). Alarmingly, students do not often communicate with each other regarding mathematics; neither do they communicate with the lecturer or the course tutor. Kenworthy and Opatska (2023) reported on the benefits of connecting with students during periods of uncertainty and crises and fostering a sense of togetherness. Also, most students (62%) do not prefer reading the relevant content sections from the textbook. We observed less convincing results for how students prepared for mathematics assessments. Less than half the sample indicated that they practised problems from revision exercises that included multiple topics (41%) and practised several problems on each topic (39%). Students mostly prefer to read or watch the content posted by the course lecturer (either lecture notes or videos).

In Table 7, we summarised the result of the Chi-square test of independence for the eleven questions related to students' self-directed learning habits and their passing of the course. We found that four questions (question numbers 23, 25, 30 and 35, see Appendix) had a strong statistical relationship with passing the course (p-values < 0.05). These factors were (i) reading and watching online material (p-value = 0.0412), (ii) attending in-person contact sessions (p-value = 0.0281), (iii) downloading and reading the learning guide (p-value = 0.0213), and (iv) reviewing marked test scripts (p-value = 0.0010) and one factor (question 34), namely "How do I study for a mathematics test or exam" showed a weak relationship with course success, where the other factors showed no statistical relationship with course success.

To further assess the relationship in the responses for students who failed versus those who passed, we display the proportion of responses for the four significant questions, conditioning on whether the students passed or failed the course, see Figure 3.

Table 7: Results for the Chi-squared independent tests linking students' self-directed learning habits and course results

Question ID		***p*-value**
23	I have been reading and/or watching the online material provided: *(agree, neutral, disagree)*	0.0412
24	I can keep up with the weekly schedule and have been reading and/or watching the online material in the week it is released: *(agree, neutral, disagree)*	0.2452
25	I have been attending in-person contact sessions (classes and/or tutorials) regularly: *(agree, neutral, disagree)*	0.0281
27	Thus far, on average, I have spent the following number of hours per week (reading through the slides and textbook, watching pre-recorded videos, attending in-person contact sessions, practising tutorial problems, and completing assessments) studying mathematics: *(less than one-hour p/w, 1-hour p/w, …, 6+ hours p/w)*	0.6123

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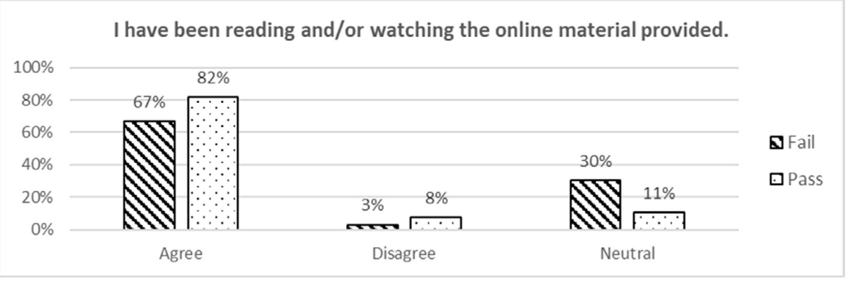
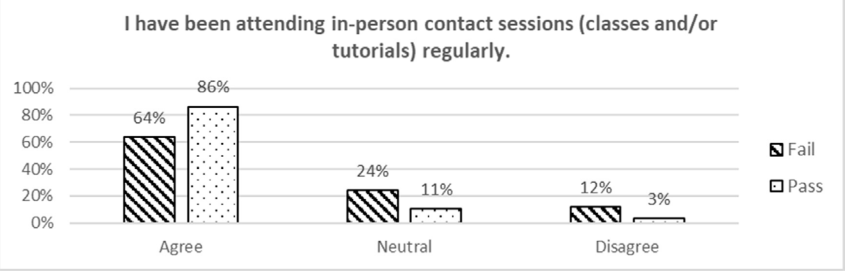
Question ID		*p*-value
28	Describe your study habits: *(I spend more time per week on mathematics than on any of my other modules; I spend roughly the same amount of time per week on all the modules I am registered for, etc.)*	0.3613
30	Did you access the learning guide? *(I downloaded the learning guide and read it carefully; I downloaded the learning guide but did not read it; I did not download the learning guide).*	0.0213
31	How do I navigate difficulty with a particular content area? *(Master the content on my own, leave that section of the work and continue with the next section, consult with a lecturer, etc.)*	0.1494
32	Do I make use of a study group to prepare for a mathematics test or exam? (Study on my own, study with one or more fellow students, *etc.)*	0.6663
34	How do I study for a mathematics test or exam? *(I do not look at the solution or a hint until I have completed an attempt and have a suggested solution; I spend only a few minutes trying to solve the problem before looking at the solution for a hint, etc.)*	0.0905
35	When my marked script becomes available for collection, or the mark of an assessment is posted, I revise the script: *(As soon as possible, I collect my script or check my mark, then look at my attempt and compare this with the ideal solution to see where I went wrong and to learn from my mistakes; I do not collect my script or check my mark, etc.)*	0.0010
36	I take all the assessments for mathematics seriously and prepare equally for all, whether it is a weekly assignment, quiz or a semester test: *(agree, neutral, disagree)*	0.4971

Note: The variables with a significant relationship (*p*-value < 0.05) with course success are highlighted.

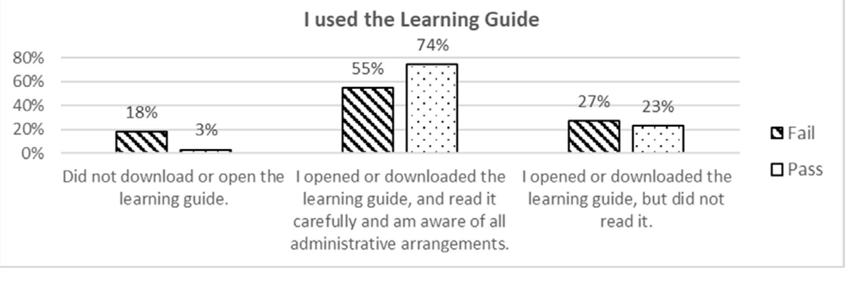
The results showed that reading and watching the online material provided by the course lecturer (*p*-value = 0.0412) yielded a significantly higher proportion of students who passed the course than those who failed (82% and 67%, respectively, see Figure 3(a)). Related to attending in-person contact sessions (*p*-value = 0.0281), we observed that a higher proportion of students who passed the course indicated that they attended the sessions (86%) than those who failed (64%), as shown in Figure 3(b). Whether the students read the learning guide carefully showed a significant relationship with passing the course (*p*-value = 0.0213). Usually, the learning guide provides valuable information to students regarding the course outline and organisation, learning outcomes, assessment criteria, and content, which allows students to be better prepared for the course. From Figure 3(c), it can be seen that a higher proportion of students who failed did not open or download the learning guide (18%) compared to the students who passed (3%). Further, the students who passed the course showed a higher proportion of respondents who carefully read the learning guide (74%) than those who failed (55%). The question describing students' self-regulating learning habits, which was significantly related to their success in the course, was the students' behaviour when their marked test scripts became available (*p*-value = 0.0010). In Figure 3(d), it can be seen that the sample who passed showed a significantly higher proportion of test script revision (74%) compared to the sample who failed (18%). Further, a significantly higher proportion of students who did not collect their marked scripts failed (27%) than those who passed (3%).



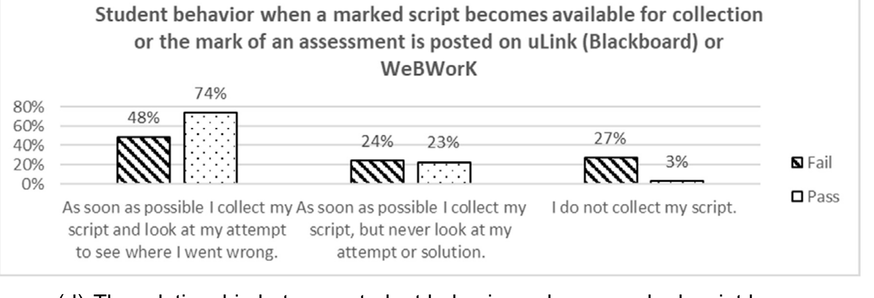
(a) The relationship between reading and/or watching the online material and course success



(b) The relationship between attending in-person contact sessions (classes and/or tutorials) regularly and course success



(c) The relationship between using the learning guide and course success



(d) The relationship between student behaviour when a marked script becomes available and course success

Figure 3: The relationship between first-year students' self-directed learning habits and course success

These results emphasise the importance of students' self-directed learning habits in achieving success in a blended learning course. Aspects such as regular engagement with the course content through attending the contact sessions, reading and watching online material, carefully reading the learning guide, and learning through reflections on mistakes (e.g., revising marked scripts) are all important factors in student success. In this study, we showed empirically that students used SDL habits, but not in all cases and situations.

The results obtained from the sample are promising and show that a blended learning environment (like the example from this study) can be used in a disruptive context. Our main results are that students' access to technology and the Internet have no significant relationship with passing the course. In contrast, students' self-directed learning habits are related to success in the course.

6. Discussion

This paper reports on empirical results collected from a self-designed questionnaire from a sample of 99 first-year mathematics students at a university in Johannesburg towards the end of the COVID-19 era (early in 2022). During this time, several regulations (by the government or university management) were implemented to stabilise the disruptive situation in tertiary education. A context-specific blended learning environment was designed, aligned with regulations, that included both synchronised and asynchronised ways of learning. The environment was well organised (both off- and online), with the content structured logically to provide a scaffold for students' learning and allow for interaction between students, tutors and lecturers. Key variables in students' learning were the availability and accessibility of technological resources (such as devices and the Internet) and students' self-directed learning habits. The relationship between key variables and official course marks was examined using the Chi-Square test of independence.

We know from former studies that tertiary mathematics students in developing countries might have unequal scenarios related to the availability and accessibility of technological resources. For example, students with access to a smartphone and at least one other device perform significantly better when learning tertiary mathematics online than students with access to only a smartphone (see Morton & Durandt, 2023, also compare Chirinda et al., 2021). Against this background, the result of our study is promising, particularly in developing countries and countries with unequal educational scenarios, showing that the availability and accessibility of technological resources did not affect students' ability to learn in this blended environment. One reason for this contradictory result might be that during the COVID period, both universities and students learnt ways to make technological resources more available and accessible.

An expected result is that self-directed learning habits in a blended environment significantly affect tertiary students' performance in mathematics. Our study highlights the educational benefits if students regularly read and watch the online material provided by course lecturers, often attend in-person contact sessions, access and carefully read the information provided in the learning guide, and take the review of their mistakes seriously. Our result confirms former reports (compare Morton & Durandt, 2023) regarding first-year students' approach to solving tertiary mathematics problems while studying online – the approach significantly affects performance. Further, the result provides empirical evidence for the Mentz and de Beer

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(2021) argument that SDL should be the gold standard in education. When interpreting the result, we realise that many students do not apply sufficient self-directed learning habits (as formerly mentioned by others, see, e.g., Quinn and Aaräo, 2020).

We know the South African educational context is multi-cultural, informed by inequalities and knowledge gaps in students' learning (see, e.g., Di Pietro, 2023; Reddy, Winnaar, Arends, Juan, Harvey, Hannan & Isdale, 2022), with multilingualism an issue in our classrooms (see, e.g., Essien, 2024). Recent findings from the international domain highlight culture-specific differences in classrooms (see, e.g., Dreher, Wang, Feltes, Hsieh, Lindmeier, 2024). In this context, the results from our study showing that English as a home language (the language of instruction at South African universities) and students' grade 12 marks are significant to performance in tertiary mathematics seems upsetting. Recent work by Lindl, Durandt and Blum (in press) also suggested a link between learning mathematics, particularly related to real-life examples, and learning in the home language.

7. Concluding remarks

The main aim of this study was to explore students' experiences and effect variables – the availability and accessibility of technological resources and students' self-directed learning habits – on learning mathematics in a context-specific blended learning environment during a time of disruption and how it affects their performance in a course. The results and conclusions can be used towards a better understanding to help navigate the complexities of disruptions.

We can use this research's lessons to inform our practice in current and future disruptive times. *First lesson*: We realise lecturers can make pedagogical changes to adapt according to new criteria if the world around us changes. *Second lesson*: We recognise the profound opportunities of a well-planned blended learning approach. *Third lesson*: We are reminded of the importance of students' home language and educational background that influences their learning in the tertiary environment. *Fourth lesson*: We are encouraged by the result that an unequal technological environment did not affect tertiary students' learning. The *fifth lesson* shows the advantages of good self-regulated learning habits.

We recognise the limitation that those participants lacking self-directed learning habits might not have volunteered to participate in the study, and students with challenges in technological resources may be underrepresented. Still, this study contributes towards the discussion in the research as called for by Borba (2021). Future research might focus more intensely on understanding the language barriers of tertiary students and how to lessen these. Another priority is to explore ways of fostering self-directed learning habits of tertiary students. To conclude, disruptions in education are like a two-sided coin, leading to a crisis on the one side and a creative opportunity on the other.

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Appendix

Questions (* indicates required question)

1. My student number is … *
2. My sex is: *
    - Male
    - Female
3. My home language is: *
    - Pedi
    - Sotho
    - Tswana
    - Swati
    - Venda
    - Tsonga
    - Afrikaans
    - English
    - Ndebele
    - Xhosa
    - Zulu
    - Other
4. If you selected ‘other’ in question 3, then please specify your home language in the space provided below. If you already selected your home language in question 3, then question 4 is not applicable to you.
5. I matriculated in: *
    - 2021
    - 2020
    - 2019
    - 2018
    - 2017
    - Before 2017
6. I completed my final school year in: *
    - Eastern Cape
    - Free State
    - Gauteng
    - KwaZulu-Natal
    - Limpopo

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- Mpumalanga
- Northern Cape
- North West
- Western Cape
- Outside of South Africa

7. If you selected ‘Outside of South Africa’ in question 6, then please specify the country where you completed your final school year in the space provided below. If you completed your final school year in South Africa, then question 7 is not applicable to you.
8. I obtained the following symbol (percentage) for Mathematics in Grade 12: *
    - 7 (80% - 100%)
    - 6 (70% - 79%)
    - 5 (60% - 69%)
    - 4 (50% - 59%)
    - 3 (40% - 49%)
    - 2 (30% - 39%)
9. I obtained the following symbol (percentage) for English in Grade 12: *
    - 7 (80% - 100%)
    - 6 (70% - 79%)
    - 5 (60% - 69%)
    - 4 (50% - 59%)
    - 3 (40% - 49%)
    - 2 (30% - 39%)
10. At the end of my Grade 12 year, I wrote: *
    - The NSC (National Senior Certificate) Grade 12 examination (typically written by South African public schools).
    - The IEB (Independent Examinations Board) Grade 12 examination (often written by private/independent schools).
    - Other (e.g., A levels).
11. If you selected ‘other’ in question 10 (meaning that you did not write the NSC or the IEB Grade 12 examinations), then please specify the examination you wrote in your final school year in the space provided below. If you took the NSC or IEB Grade 12 examinations, then question 11 is not applicable to you.
12. During the year 2020, I: *
    - Was attending high school and completed my Grade 11 year.
    - Was attending high school and completed my Grade 12 year.
    - Was registered as a student at the University of Johannesburg.
    - Was registered as a student at another tertiary institution.

- Was studying at a tertiary institution but deregistered before completing the academic year.
- Was not studying at all.

13. During the year 2021, I: *
    - Was attending high school and completed my Grade 12 year.
    - Was registered as a student at the University of Johannesburg.
    - Was registered as a student at another tertiary institution.
    - Was studying at a tertiary institution but deregistered before completing the academic year.
    - Was not studying at all.
14. If I was studying in 2020 (either at a high school or at a tertiary institution), then during the 2020 national lockdown levels 5 and 4, I: *
    - Attended online classes and returned to face-to-face classes as soon as possible.
    - Attended online classes but did not return to in-person classes for the rest of 2020.
    - Did self-study, without any online classes, and returned to in-person classes as soon as possible.
    - Did self-study, without any online classes, but was unable to return to in-person classes for the rest of 2020.
    - Did not self-study, nor attended online classes, but returned to in-person classes as soon as possible.
    - Did not self-study, nor attended online classes and was unable to return to in person classes for the rest of 2020.
15. If I was studying in 2021 (either at a high school or at a tertiary institution), then during the 2021 national lockdown level 4, I: *
    - Attended online classes and returned to face-to-face classes as soon as possible.
    - Attended online classes but did not return to in-person classes for the rest of 2021.
    - Did self-study, without any online classes, and returned to in-person classes as soon as possible.
    - Did self-study, without any online classes, but was unable to return to in-person classes for the rest of 2021.
    - Did not self-study, nor attended online classes, but returned to in-person classes as soon as possible.
    - Did not self-study, nor attended online classes and was unable to return to in person classes for the rest of 2021.
16. Do you agree or disagree with the following statement? I would say that my matric symbol is a fair reflection of my understanding of the Grade 12 Mathematics curriculum: *
    - I disagree, I understand the work better than my mark suggests.
    - I disagree, I do not understand the work as well as my mark suggests.
    - I agree, my matric symbol is a fair reflection of my understanding of Grade 12.

17. Do you agree or disagree with the following statement? I remembered the school Mathematics curriculum well, and I have been able to use the content in first-year Mathematics at University without any revision: *
    - I disagree, I needed to revise school mathematics again before studying tertiary mathematics.
    - I agree, I remembered all topics from school mathematics and no revision was required before studying tertiary mathematics.
18. The area where I live now (while studying at the University of Johannesburg) has power outages (no electricity): *
    - Almost every day.
    - At least once a week.
    - Only during official load shedding.
    - Almost never.
    - Irrelevant, since we have back-up power.
19. In 2022, I can access the internet: *
    - Any time of the 24-hour day.
    - Only during night-owl hours (typically from 00:01 until 05:00/06:00/07:00, depending on your service provider).
20. I have the following devices available to use for my studies in 2022 (please select all applicable options): *
    - A smartphone.
    - A tablet.
    - A laptop computer.
    - A desktop computer.
    - I have no personal devices.
21. If you indicated that you have no personal devices available for your studies in 2022 in question 20, please describe how you access the online materials provided in your modules in the space provided below. (e.g., I use a desktop computer in the university computer laboratories/library.)
22. I must share the device(s), available to me for online learning in 2022, with the following number of people: *
    - 0
    - 1
    - 2
    - 3 or more
23. In 2022, while studying at the University of …, I have been reading and/or watching the online material provided. *
    - Strongly disagree
    - Disagree

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- Neutral
- Agree
- Strongly Agree

24. In 2022, while studying at the University of …, I am able to keep up with the weekly schedule and have been reading and/or watching the online material in the week it is released. *
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
25. In 2022, while studying at the University of …, I have been attending in-person contact sessions (classes and/or tutorials) regularly. *
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree
26. In 2022, while studying at the University of …, if you have not been attending in-person contact sessions regularly, please provide the main reason(s) for your absence.
27. Thus far, while studying at … in 2022, on average I have spent the following number of hours per week (reading through the slides and textbook, watching pre-recorded videos, attending in-person contact sessions, practicing tutorial problems and completing assessments) studying Mathematics: *
    - Less than an hour per week.
    - 1 hour per week.
    - 2 hours per week.
    - 3 hours per week.
    - 4 hours per week.
    - 5 hours per week.
    - 6 or more hours per week.
28. Which of the following statements best describes your study habits: *
    - I spend more time per week on Mathematics than on any of my other modules.
    - I spend roughly the same amount of time per week on all the modules I am registered for.
    - There are other modules that I am registered for that I spend more time on per week than on Mathematics.

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29. The time I spend on Mathematics weekly, is used to: *
    - Read through the lecture slides and notes.
    - Read the relevant section in the textbook.
    - Watch videos (posted by the lecturers or on YouTube).
    - Practice tutorial problems.
    - Complete assessments.
    - Attending in-person contact sessions.
    - Communicate with the lecturers or tutors about the content and tasks.
    - Communicate with my friends about the content and tasks.
30. At the start of the semester, I: *
    - Did not download or open the learning guide.
    - I opened or downloaded the learning guide but did not read it.
    - I opened or downloaded the learning guide and read it carefully and am aware of all administrative arrangements.
31. When I have trouble with a particular content area, I mostly prefer to: *
    - Master the content on my own.
    - Ask a fellow student for help.
    - Consult with a tutor.
    - Consult with a lecturer.
    - Leave that section of the work and continue with the next section.
32. When I study for a Mathematics test or exam, I: *
    - Study on my own.
    - Study with one or more fellow students.
    - Spend some of my time studying on my own and some of my time studying with one or more fellow students.
33. When I study for a Mathematics test or exam, my preparation includes: *
    - I read the relevant sections in the textbook.
    - I read the class notes and slides.
    - I watched video examples.
    - I write down the theory (rules and theorems) to remember them.
    - I practice only a few problems on each topic.
    - I practice several problems on each topic.
    - I practice problems from revision exercises that include multiple topics.
    - I read through the memorandums of past papers without attempting the problems myself.
    - I attempt the problems from past papers before looking at the solutions.

34. While studying for a Mathematics test or exam, I attempt a Mathematics problem, and: *
    - If I do not know how to solve the problem, I immediately look at the solution.
    - Spend only a few minutes trying to solve the problem before looking at the solution for a hint.
    - I do not look at the solution, nor a hint until I have completed an attempt and have a suggested solution.
35. Which of the following best describe your behaviour when a marked script becomes available for collection, or the mark of an assessment is posted on the electronic learning environment: *
    - As soon as possible I collect my script or check my mark, but never look at my attempt or the ideal solution.
    - As soon as possible I collect my script or check my mark, but only look at my attempt again before another major assessment.
    - As soon as possible I collect my script or check my mark and look at my attempt to see where I went wrong.
    - As soon as possible I collect my script or check my mark, then look at my attempt and compare this with the ideal solution to see where I went wrong and to learn from my mistakes.
    - I do not collect my script or check my mark.
36. Do you agree or disagree with the following statement? I take all the assessments for Mathematics seriously and prepare equally for all, whether it is a weekly assignment or quiz or a semester test.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree